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Buffers balancing of buffer-aided relays in 5G non-orthogonal multiple access transmission internet of things networks

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ABSTRACT

Buffer-aided cooperative non-orthogonal multiple access (NOMA) enhances the efficiency of utilizing the spectral by allowing more users to share the same resources to establish massive connectivity. This is remarkably attractive in the fifth generation (5G) and beyond systems, where a massive number of links is essential like in the internet of things (IoT). However, the capability of buffer cooperation in reducing the outage is limited due to empty and full buffers, where empty buffers can not transmit and full buffers can not receive data packets. Therefore, in this paper, we propose balancing the buffer content of the interconnected relays, so the buffers that are more full send packets to the emptier buffers, hence all buffers are more balanced and farther from being empty or full. The simulations show that the proposed balancing technique has improved the network outage probability. The results show that the impact of the balancing is more effective as the number of relays in the network is increased. Furthermore, utilizing the balancing with a lower number of relays may lead to better performance than that of more relays without balancing. In addition, giving the balancing different levels of priorities gives different levels of enhancement.

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1. INTRODUCTION

Wireless communication is currently one of the most crucial forms of communication. As a result, the unprecedented growth in the number of online devices is making wireless communication in future applications increasingly complex. For instance, the internet of things (IoT), which relies on fifth-generation (5G) and beyond technologies, demands extensive wireless connectivity while ensuring a low probability of outages. However, these requirements cannot be fulfilled by the existing infrastructure [1], [2].

In conventional wireless communication, orthogonal transmission is typically used, where each link between transmitters and receivers is assigned a unique frequency band, time-slot, or code to prevent interference between different links. However, this method reduces spectral efficiency and is inadequate for the future of communication systems [3]. As a result, non-orthogonal multiple access (NOMA) has been introduced to enable simultaneous use of the same resources. Unlike orthogonal schemes, NOMA allows multiple users to transmit using the same code, time, and frequency, but with varying power levels. Specifically, NOMA dedicates less power to users with good channel conditions, who are referred to as strong users, as they can decode their messages with less power. With advances in signal processing, NOMA becomes feasible with sophisticated receivers, which enable strong users to eliminate interference from sharing the same resources through successive interference cancellation (SIC) [4]. Since higher power is allocated to weaker users (with poorer channels), they can treat the strong user's signal as interference and successfully decode their own. As a result, NOMA enables more users to share the same resource, such as frequency or time slots, with different power levels, thereby enhancing spectral efficiency [5]. Hence, NOMA is an attractive solution to achieve the massive connectivity required for 5G applications such as the IoT [6]-[8]. At present, NOMA is being considered for inclusion in the 3GPP Release 16 standards for 5G systems [9].

Relay techniques are another crucial method for enhancing network performance [10]. Relays help transmit packets from the source to users by providing an alternative path between the source and the destination. As a result, long-term evolution (LTE) Release 10 has acknowledged the role of relay node cooperation as a key component in enabling modern wireless communications [11]. There are two primary types of relaying: amplify-and-forward (AF) and decode-and-forward (DF). In the AF method, the relay node amplifies the received signal and forwards it to the users, which simplifies its implementation. However, this approach also amplifies any noise present in the signal. In contrast, the DF method allows the relay node to decode the received signal, re-encode it, and then send the decoded signal to the users. While DF resolves the issue of noise amplification, it demands higher channel gains to achieve acceptable quality of service (QoS), making it more resource-intensive than AF [12]. The advantage of relay selection in networks with multiple relays lies in its competitiveness with multiple-input, multiple-output (MIMO) systems, while remaining simpler to implement. This is because relay selection does not require complex physical layer techniques like synchronization, which are necessary in MIMO systems [13], [14].

Given the effectiveness of relays in mitigating communication link losses, the integration of cooperative relaying with advanced techniques has been extensively explored in the literature [15]. Non-orthogonal multiple access (NOMA) has been successfully implemented in cooperative relay networks, with several studies suggesting the use of conventional (non-buffer) relay selection for cooperative NOMA [16]. In [17], a two-stage relay selection strategy is proposed to maximize the data rate for users. The analysis and simulation results demonstrate that this approach outperforms non-cooperative NOMA. A recent innovation in cooperative networks is the use of buffer-aided relays [18], which allows for better alignment of transmissions with stronger links compared to traditional non-buffer relay selection methods [19]. As a result, buffer-aided techniques have become the state-of-the-art in cooperative NOMA networks. Additionally, [20] introduced an adaptive link selection strategy for a single-relay NOMA network, assuming an infinite buffer size. The analysis reveals that this system achieves lower outage rates and higher throughput compared to conventional relaying schemes in NOMA.

In real-world scenarios with limited buffer capacities, buffers often experience frequent states of being either full or empty. The performance of buffer-aided cooperative relay networks is heavily dependent on the number of packets stored in the buffers, as this directly dictates the buffer's state. When a relay buffer is either full or empty, the corresponding source-to-relay or relay-to-user link becomes unavailable for packet transmission or reception, respectively [21]. In [22], the outage probability is defined as the likelihood that either the source-to-relay link cannot support the NOMA data rate or the relay-to-user links are unable to transmit the NOMA data. As noted in [23], finding an optimal protocol that minimizes outage probability while adhering to a specific delay constraint remains an unresolved challenge, even in the simplest form of buffer-aided relay networks. Consequently, developing the ideal selection scheme for relays with finite, practical buffer sizes remains an open research problem. Based on the achieved outage probability, the best available relay selection schemes consider the buffer contents (states) in addition to the links states as well. Such selection schemes prioritize relays based on target buffer length to minimize the occurrence of full and empty buffers. However, to the best of the author's knowledge, none of the available studies has considered transferring data packets between relays so the buffers that are closer to be full help other buffers to avoid being empty, we call this process the balancing. Accordingly, motivated to fill this gap in the literature and to minimize the outage probability by using buffer-aided relays with NOMA and get closer to realizing the IoT networks. To summarize, the key novelty of this article is to apply the balancing to buffer-aided cooperative NOMA network to reduce the outage probability. The main contributions of this article are summarized as follows: i) proposing a novel relay content balancing to reduce the occurrence of empty and full buffers; ii) Studying the impact of the balancing with various numbers of relays on the NOMA network outage probability; and iii) studying the outage probability of the network under prioritizing receiving packets over the balancing.

The rest of the article is organized as follows: the system model for the suggested balanced buffer-aided cooperative NOMA networks is in section 2. The performance analysis of the balanced buffer-aided relay is presented in section 3. Simulation trials of the proposed system along with comparison with other available solutions are discussed in detail in section 4. Finally, the conclusion is presented in section 5.

2. SYSTEM MODEL

The system model of the proposed balanced buffer-aided cooperative NOMA network is shown in Figure 1. Figure 1 illustrates a source node S, k half-duplex DF buffer-aided relays, $k = 1, 2, 3...., K$, with R_1 is the selected relay with enough packets for transmitting via NOMA to the two users U_1 and U_2 simultaneously. The system model can be extended to any number of users as in [24]. The interconnection between relays in Figure 1, assures the balancing of data packets to avoid full and empty buffers. So, the relay with a longer queue can transfer packets to other relays as shown for R_1 and R_2. It is worth noting that R_2 with an empty buffer is not connected to the users and the source is not connected to R_1 as it has a full buffer.

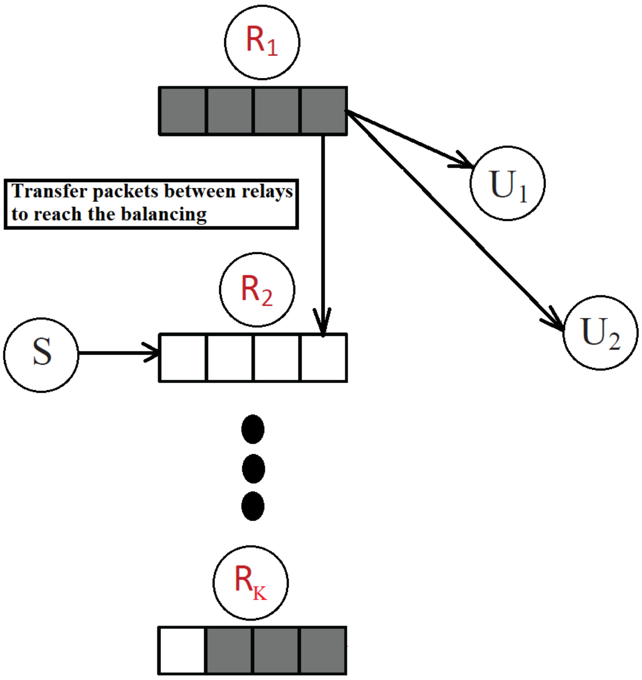

Figure 1. Balanced buffer-aided cooperative NOMA network

The relay R_k has a L-size buffer to store the packets. The source-to-relay $S - R_k$, source-to-users $S - U_m$ (m denotes the user number) and relay-to-users $R_k - U_m$ links have the channel coefficients h_{srk}, h_{su_m} and h_{rku_m}, respectively. The channels are modeled with flat Rayleigh fading coefficients, which remain constant during each time-slot but vary randomly across different time-slots. For simplicity, P_t denotes the transmit power at all transmitting nodes (whether source or relay), and σ^2 represents the noise variance at all receiving points. The target rate for data transmission is assumed to be constant, denoted by ϵ. If the capacity of a link meets or exceeds ϵ, the link is considered active and capable of supporting the transmission. If the capacity is lower than ϵ, the link is inactive and transmission cannot occur, meaning the link is in outage. Due to shadowing effects, the direct link between the source S and user U_m, denoted $S - U_m$, is assumed to be blocked. All nodes are assumed to have information about the states of all links.

2.1. OMA transmission

At time-slot t, channel capacities are calculated as (1):

$$C_{sr_k}(t) = \log_2 (1 + \gamma_{sr_k}(t)), \;\; C_{r_k u_m}(t) = \log_2 (1 + \gamma_{r_k u_m}(t)), \tag{1}$$

where $\gamma_{sr_k}(t) = \frac{P_t}{\sigma^2}|h_{sr_k}(t)|^2$ and $\gamma_{r_k u_m}(t) = \frac{P_t}{\sigma^2}|h_{r_k u_m}(t)|^2$. The channel gains $|h_{sr_k}(t)|^2$ and $|h_{r_k u_m}(t)|^2$ are assumed to follow an exponential distribution, with mean values $\theta_{sr_k} = E[|h_{sr_k}(t)|^2]$ and $\theta_{r_k u_m} = E[|h_{r_k u_m}(t)|^2]$, where $E[.]$ denotes the expectation operator. Both $\gamma_{sr_k}(t)$ and $\gamma_{r_k u_m}(t)$ also follow exponential distributions, with means $\bar{\gamma}_{sr_k} = \frac{P_t}{\sigma^2}\theta_{sr_k}$ and $\bar{\gamma}_{r_k u_m} = \frac{P_t}{\sigma^2}\theta_{r_k u_m}$, respectively. Thus, $\gamma_{sr_k}(t)$, $\gamma_{su_m}(t)$, and $\gamma_{r_k u_m}(t)$ represent the instantaneous signal-to-noise ratios (SNRs), while $\bar{\gamma}_{sr_k}$ and $\bar{\gamma}_{r_k u_m}$ are the average SNRs for the channels $h_{sr_k}(t)$ and $h_{r_k u_m}(t)$, respectively. As mentioned earlier, when the link capacity falls below the target data rate, an outage occurs. This outage is calculated using the fact that both $\gamma_{sr_k}(t)$ and $\gamma_{r_k u_m}(t)$ follow exponential distributions. Their cumulative distribution functions (CDFs) are given by (2):

$$P\{\log_2(1+\gamma_{sr_k}(t)) < \epsilon\} = 1 - exp^{\left(-\frac{2^\epsilon - 1}{\bar{\gamma}_{sr_k}}\right)}$$
$$P\{\log_2(1+\gamma_{r_k u_m}(t)) < \epsilon\} = 1 - exp^{\left(-\frac{2^\epsilon - 1}{\bar{\gamma}_{r_k u_m}}\right)} \quad (2)$$

2.2. NOMA transmission

The outage analysis for the cooperative NOMA network is detailed below. In networks utilizing orthogonal transmission, an outage occurs when the link capacity drops below the required data rate. In the case of NOMA, where transmission occurs from R_k to users, it is necessary for the relay R_k to have received the packets from both users before NOMA can be implemented. As stated in [19], NOMA can only be utilized if the link between S and R_k is capable of simultaneously transmitting both packets. For the $S \to R_k$ link, if it meets,

$$C_{sr_k}(t) \geq 2\epsilon, \quad (3)$$

this makes the outage of the $S - R_k$ link $P\{\log_2(1+\gamma_{sr_k}(t)) < 2\epsilon\} = 1 - exp^{\left(-\frac{2^\epsilon - 1}{\bar{\gamma}_{sr_k}}\right)}$. Conversely, for the $R_k \to U_m$ link, where $m = 1$ or 2, NOMA enables the simultaneous transmission of packets to both U_1 and U_2. The combined NOMA symbol at R_k is expressed as (4),

$$x_{r_k}(t) = \sqrt{\alpha} x_{r_{k,1}}(t) + \sqrt{1-\alpha} x_{r_{k,2}}(t), \quad (4)$$

where $x_{r_{k,1}}(t)$ and $x_{r_{k,2}}(t)$ are data for users U_1 and U_2 respectively, and $0 \leq \alpha \leq 1$ is the power allocation factor. Then the received signal at U_m is given by (5),

$$y_m(t) = \sqrt{\alpha P_t} h_{r_k u_m}(t) x_{r_{k,1}}(t) + \sqrt{(1-\alpha)P_t} h_{r_k u_m}(t) x_{r_{k,2}}(t) + n_m(t), \quad m = 1, 2, \quad (5)$$

where $n_m(t)$ is the noise at user U_m. When NOMA is applied, when $\gamma_{r_k u_1}(t) > \gamma_{r_k u_2}(t)$, the SNR to decode $x_{r_{k,2}}(t)$ at U_2 is given by (6),

$$SINR(x_{r_{k,2}}(t)) = \frac{(1-\alpha)\gamma_{r_k u_2}(t)}{\alpha\gamma_{r_k u_2}(t) + 1}. \quad (6)$$

Because $\gamma_{r_k u_1}(t) > \gamma_{r_k u_2}(t)$, $x_{r_{k,2}}(t)$ can also be decoded at U_1 if it can be decoded at U_2. Dropping $x_{r_{k,2}}(t)$ from the arrived signal at U_1 by SIC, the sufficient SNR to decode $x_{r_{k,1}}(t)$ at U_1 is given by (7),

$$SNR(x_{r_{k,1}}(t)) = \alpha\gamma_{r_k u_1}(t). \quad (7)$$

Following similar procedures as those in [21], the condition that there exists an α to support NOMA transmission to both U_1 and U_2 (i.e. $\log_2(1 + SINR(x_{r_{k,2}}(t)) \geq \eta$ and $\log_2(1 + SNR(x_{r_{k,1}}(t)) \geq \eta)$ is given by (8), (9),

$$\frac{(1-\alpha)\gamma_{r_k u_2}(t)}{\alpha\gamma_{r_k u_2}(t) + 1} \geq 2^\eta - 1, \quad (8)$$

$$\alpha\gamma_{r_k u_1}(t) \geq 2^\eta - 1, \quad (9)$$

from (8) and (9),

$$\frac{2^\eta - 1}{\gamma_{r_k u_1}(t)} \leq \alpha \leq \frac{1}{2^\eta}\left(1 - \frac{2^\eta - 1}{\gamma_{r_k u_2}(t)}\right), \quad (10)$$

$$\gamma_{r_k u_2}(t) \geq \frac{(2^\eta - 1)\gamma_{r_k u_1}(t)}{\gamma_{r_k u_1}(t) - 2^\eta(2^\eta - 1)}, \qquad \text{if } \gamma_{r_k u_1}(t) > \gamma_{r_k u_2}(t). \tag{11}$$

Similarly, if $\gamma_{r_k u_1}(t) < \gamma_{r_k u_2}(t)$, NOMA condition becomes,

$$\gamma_{r_k u_1}(t) \geq \frac{(2^\eta - 1)\gamma_{r_k u_2}(t)}{\gamma_{r_k u_2}(t) - 2^\eta(2^\eta - 1)}. \tag{12}$$

If the signal-to-noise ratio (SNR) for the $R_k \to U_m$ links ($m = 1$ or 2) is insufficient to meet the conditions in (11) or (12), then NOMA transmission either becomes unfeasible or inefficient. In such cases, if $C_{r_k u_m}(t) > \eta$, OMA can be utilized to transmit a single packet to U_m. By following procedures similar to those outlined in [22], we derive,

$$\begin{aligned} P_{k,(m,n)} =& \frac{1}{\bar{\gamma}_{r_k u_m}} e^{\left(-\frac{(2^\eta-1)\bar{\gamma}_{r_k u_m} + (2^{2\eta} - 2^\eta)\bar{\gamma}_{r_k u_n}}{\bar{\gamma}_{r_k u_m}\bar{\gamma}_{r_k u_n}}\right)} \int_{2^\eta - 1}^{\infty} e^{\left(-\frac{x}{\bar{\gamma}_{r_k u_m}} - \frac{2^\eta(2^\eta-1)^2}{\bar{\gamma}_{r_k u_n} x}\right)} \mathrm{d}x \\ & - \frac{\bar{\gamma}_{r_k u_n}}{\bar{\gamma}_{r_k u_m} + \bar{\gamma}_{r_k u_n}} e^{\left(-\frac{(2^\eta-1)(\bar{\gamma}_{r_k u_m} + \bar{\gamma}_{r_k u_n})(2^{2\eta}+2^\eta)}{\bar{\gamma}_{r_k u_m}\bar{\gamma}_{r_k u_n}}\right)}, \end{aligned} \tag{13}$$

where $(m, n) \in \{(1, 2), (2, 1)\}$.

Although NOMA transmission brings benefits to the network by increasing the throughput, it imposes some difficulties by raising the required channel gain to avoid outage (above 2ϵ). Adding to this outage potential, the outage caused by empty and full buffers raises the outage to unacceptable levels. To reduce the occurrence of empty and full buffers, this paper proposes the balancing of the buffers by moving packets from more full buffers to emptier buffers. The balancing can be done on different levels. For instance, the balancing is performed when the network is in outage so no more burden is added to the network by balancing. This level of balancing is preferable when bad channel gains are the dominant cause of the outage. On the other hand, it is desirable to give higher priority for the balancing in good channels gains where the fullness and emptiness of buffers is the dominant cause for outage, more details on this in section 4.

3. PERFORMANCE ANALYSIS

Buffer-aided relays play a key role in reducing the outage probability, which in turn improves system throughput. However, when the buffers are either completely full or empty, the system performance suffers, leading to a higher probability of an outage. This section presents an analytical comparison highlighting the benefits of a balanced buffer-aided relay system over an unbalanced one. In the context of each buffer-aided relay, the number of stored data packets determines its state. Assuming there are K relays, each with a buffer size of L, there are $(L + 1)^K$ distinct possible states. Each of these states affects the availability of the $S - R_k$ and $R_k - U_m$ links. Specifically, the $S - R_k$ link is available when the receiving buffer is not full, while the $R_k - U_m$ link is available when the transmitting buffer is not empty. The state vector for the l-th state is defined as (14),

$$s^{(l)} = [s_1^{(l)}, s_2^{(l)}, \cdots, s_k^{(l)}], \quad l = 1, \cdots, (L + 1)^k, \tag{14}$$

where $s_k^{(l)}$ is the length of the buffer at R_k at state $s^{(l)}$.

Considering all possible states, the outage probability is defined as the likelihood that the system remains in the same state, implying that no communication (either transmission or reception) takes place during the current time-slot. Hence, the outage probability for the buffer-aided system can be expressed as (15),

$$P_{out} = \sum_{i=1}^{(L+1)^K} P_{out}^{\mathbf{s}^{(i)}} \pi_i. \tag{15}$$

where π_i denotes the stationary probability of state $s^{(i)}$, and $P_{out}^{s^{(i)}}$ represents the outage probability at state $\mathbf{s}^{(i)}$.

In buffer-aided relays, the buffer states are modeled as a discrete-time Markov chain, with the transition matrix A capturing the state transitions within a space of $(L+1)^M \times (L+1)^M$. The entry A_{ij} represents the probability of transitioning from state $s^{(j)}$ at time t to state $s^{(i)}$ at time $t+1$:

$$A_{ij} = P(X_{t+1} = s^{(i)} | X_t = s^{(j)}) \tag{16}$$

The Markov chain is both irreducible and aperiodic. A chain is irreducible if all states are reachable from any other state, and aperiodic if there is a nonzero probability of remaining in any given state, as discussed in [25]-[26]. As shown in [27], for an irreducible and aperiodic Markov chain, the stationary state probability vector can be calculated as (17),

$$\boldsymbol{\pi} = (A - I + B)^{-1} b, \tag{17}$$

where $\boldsymbol{\pi} = [\pi_1, \pi_2, \cdots, \pi_{(L+1)}]$ is the stationary probability vector, π_i is the probability of being in state s_i, $b = [1, \cdots, 1]^T$, I is the identity matrix, and B is an $(L+1) \times (L+1)$ matrix filled with ones. Using this, we can determine the outage probability of the buffer-aided relay system when the Markov chain remains in the same state as (18):

$$P_{out} = \sum_{i=1}^{(L+1)^M} \pi_i A_{ii} \tag{18}$$

where A_{ii} are the diagonal elements of A.

Assuming that all links are independent and identically distributed (i.i.d.), if balancing is successfully applied to prevent buffer underflow or overflow, the outage probability of any given state is,

$$(1 - e^{-\frac{2^{2\epsilon}-1}{\bar{\gamma}_{SR_k}}})^{O_{s^{(l)}}^{SR_k}} \times (P_{k,(m,n)})^{O_{s^{(l)}}^{R_k U_m}} \tag{19}$$

where $O_{s^{(l)}}^{SR_k}$ denotes the number of available $S - R_k$ links at state $s^{(l)}$, and $O_{s^{(l)}}^{R_k U_m}$ is the number of available $R_k - U_m$ links at state $s^{(l)}$. On the other hand, if the balancing is not applied, for each full buffer the number $O_{s^{(l)}}^{SR_k}$ is reduced by one. Similarly, for each empty buffers, the number $O_{s^{(l)}}^{R_k U_m}$ is reduced by one. Since we are dealing with probabilities the numbers $(1 - exp(-\frac{2^{2\epsilon}-1}{\bar{\gamma}_{SR_k}}))$ and $(P_{k,(m,n)})$ are less than one, so decreasing there powers ($O_{s^{(l)}}^{SR_k}$ and $O_{s^{(l)}}^{R_k U_m}$ respectively) increases the outcome of (19), which increases the outage probability of the network. This shows the benefits of avoiding empty or full buffers via balancing.

4. SIMULATION RESULTS

This section discusses the results of the experimental simulations conducted to validate the analysis presented earlier. We evaluate the effectiveness of the proposed interconnection between buffer-aided relays in a cooperative NOMA network. For the simulations, we assume that the noise variance, σ^2, is normalized to 1, and we adopt the data rate $\epsilon = 2$ bps/Hz, as suggested in [22]. Additionally, the buffer size is set to $L = 5$.

Firstly, we show the effect of the balancing of the buffer content on the outage probability. The positive impact of the balancing on the outage probability is obvious in Figure 2. Figure 2 shows the comparison between balanced and non-balanced cases for two relays and three relays networks. The balancing enhances the network performance in the two cases. It is worth noting that with more relays the importance of the balancing increases, this can be observed by noticing a higher impact of the balancing on the three relays case. This is true because avoiding empty or full buffer increases the degree of freedom, hence the diversity gain is increased as well. Taking into account a higher number of available buffers leads to a higher degree of freedom. For instance, to get a 0.1 outage probability in the two relay cases, the required SNR is about 13.5 dB and 14.5 dB for non-balancing and balancing cases respectively. So the reduction in the required SNR is 1 dB. If we do the same comparison in the case of three relays, the reduction is above 3 dB which is higher than that of the two relays case.

Figure 3 stresses the importance of the balancing as it shows the impact of the balancing on the system throughput. For the 3 relay case the throughput improvement can be higher than 0.5 packet per time-slot at 10 dB SNR. Based on the proportionality between outage probability and throughput, we can infer that the improvement of the balancing becomes more effective by adding more relays to the network, similar to what happened with the outage probability in Figure 2.

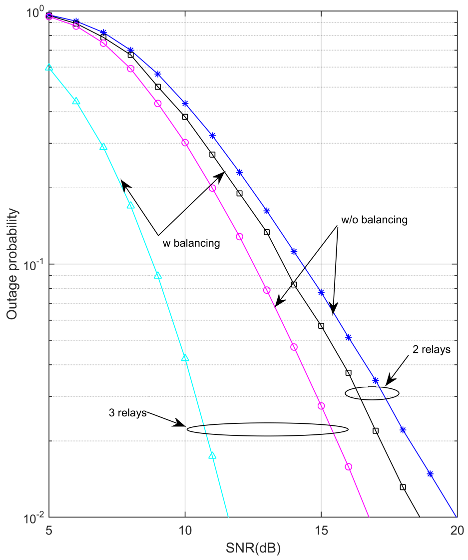

Figure 2. The impact of the buffer content balancing on the outage probability in two and three relays networks

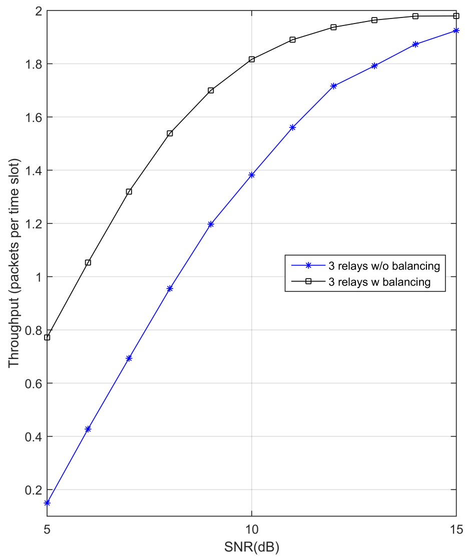

Figure 3. Throughput comparison of balancing and non-balancing in three relays network

Another significant benefit of applying balancing in buffer-aided relays is achieving the performance of a large number of relays with a minimal number of relays. This reduction in number of relays reduces the network complexity and cost as well. The decline in outage probability can be achieved by increasing the number of relays, see Figure 2. However, the same effect can be realized with the balancing as shown in Figure 4. The non-balancing three relays outperform the balancing two relays. But, as mentioned above, the effectiveness of the balancing increases with more relays, this is exactly the case in Figure 4, the balancing three relays outperform the non-balancing four relays network.

After studying the benefits of considering the balancing of the buffer content, it is important to study the impact of applying the balancing in different approaches. Two mechanisms are shown in Figure 5. In the first one, the balancing is prioritized over the receiving, which means no receiving (relays received from the source) can take place before the content of the buffer is balanced. As in [28], giving higher priority to the transmission from relays to the users and lower priority to the receiving (relays receive from source) is important to enhance the outage probability of the network. Therefore, in prioritize balancing, the transmission has the highest priority then the balancing is given a higher priority than the receiving. It is worth noting that the balancing itself causes the network to be outage according to the outage definition where the network is outage in a specific time slot if no data packets are received or transmitted by relays during the time slot. Another mechanism is to give higher priority to transmission and receiving and perform balancing only when no transmission or receiving is possible. Figure 5 shows that prioritizing receiving and performing balancing only when the network is in an outage is better than giving higher priority to balancing. This is true as prioritize balancing causes outages and giving balancing lower priority to happen only when the network is in outage which causes no more outages. If it is feasible to dedicate a separate channel for communication between relays, then balancing can be always performed (not in outage only) without causing more outages.

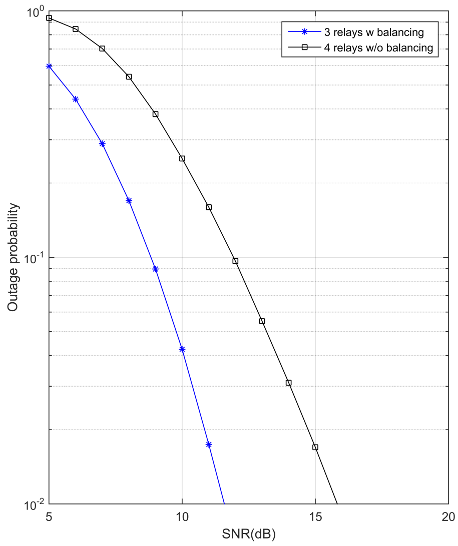

Figure 4. Outage probability comparison between the non-balancing 4 relays network and the balancing 3 relays network

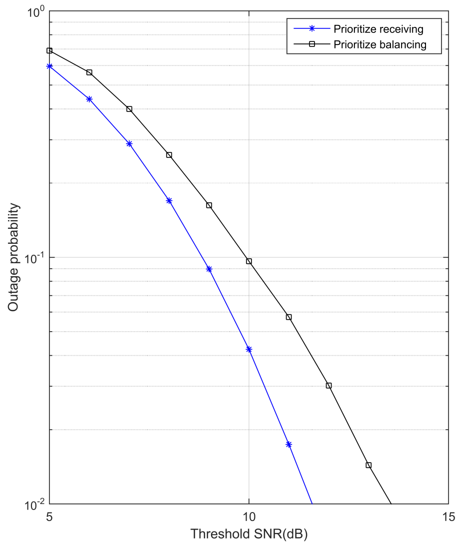

Figure 5. The impact of prioritizing reception or balancing on the outage probability of the network

5. CONCLUSION

This study proposes employing balancing in buffer-aided relays in cooperative NOMA networks. This is urged due to the performance limitations of buffer-aided relays when relays cannot receive or transmit with full or empty buffers respectively. The proposed balancing technique improves the network performance by making full or empty buffers less likely to happen. As the number of buffer-aided relays is increased, the outage probability is decreased. The impact of the balancing on the outage probability increases with more relays. In particular, the balancing has an impact similar to and better (in some scenarios) than adding more non-balancing networks. In addition, adding more relays could be costly, while the balancing can be performed in the available resources without added cost. Finally, prioritizing the balancing can be done at different levels with different outcomes. For instance, giving the balancing the lowest priority by performing it only when the network cannot transmit or receive is capable of reducing the outage probability. Allowing the balancing to be performed all the time by dedicating a channel for the balancing can achieve better results.

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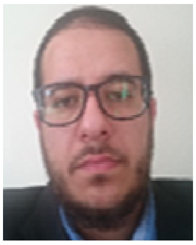

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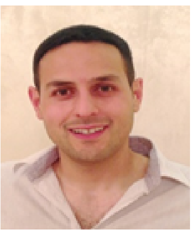

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